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Reliability Analysis of Fatigue Fracture of Wind Turbine Drivetrain Components

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Abstract

One of the main challenges for the wind turbine industry currently, is to reduce the cost of levelized energy, especially for offshore wind. Failures in the wind turbine drivetrain generally result in the second largest down times of the wind turbine, hence significantly increasing the cost of operation and maintenance. The manufacturing of casted drivetrain components, like the main shaft of the wind turbine, commonly result in many smaller defects through the volume of the component with sizes that depend on the manufacturing method. This paper considers the effect of the initial defect present in the volume of the casted ductile iron main shaft, on the reliability of the component. The probabilistic reliability analysis conducted is based on fracture mechanics models. Additionally, the utilization of the probabilistic reliability for operation and maintenance planning and quality control is discussed.

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Keywords: wind turbine; drivetrain; proabilistic reliability analysis; fracture mechanics.

1. Introduction

The constantly increasing energy demand together with environmental consciousness, poses new challenges to develop economically competitive and highly capable renewable energy devices. The use of offshore wind turbines is widely regarded as one of the most favorable solutions to the aforementioned challenges.

However, offshore wind turbines located in deep waters are exposed to harsh environmental conditions including extreme winds, temperatures, waves and lightning storms. These severe conditions significantly increase the cost of

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offshore wind project erection, operation and maintenance (O&M) and reduces the reliability of the wind turbine. Therefore, the levelized cost of energy (LCOE) of electricity produced by offshore wind turbines is relatively high according to the research performed in [1]. Furthermore, experience shows that the offshore O&M may contribute up to 30% of the COE [2].

The cost of offshore O&M increases due to the dependency on the weather condition, vessel availability in addition to the energy losses due to the down time of the turbine. Eventual failures in the wind turbine drivetrain module may typically result in around 25% of the total down time [3]. Larger energy losses are observed only from the failure in the power module, however drivetrain failures are usually more expensive to repair due to crane costs.

This paper addresses the influence of the defects, usually present at the cast iron components, on the reliability of the wind turbine and the utilization of developed methods for O&M planning and quality control. The wind turbine main shaft, in this paper, is regarded as the component of interest. Hence, the crack propagation models are developed with the assumption that the pre-existing defects are located in the main shaft and consequently subjected to lifetime loading history of the component.

Crack propagation models were developed using two fracture mechanics methods, namely the Paris and Walker laws [4,5]. The main difference between the aforementioned models being that the Walker laws takes into account the influence of the mean stresses, which are known to be important when using the more simple SN-curve approach for design. Thus, the influence of the mean stress on the fatigue fractures is investigated in the following analysis. The crack propagation models are used as a basis for the probabilistic reliability analysis. The probabilistic approach is chosen due to the fact that mechanical drivetrain components designed by a code based, deterministic approach is generally unable to account for the random variabilities inherently present in the design variables. A probabilistic model of uncertainties associated with the considered crack propagation models is developed and applied to estimate the probability of failure, in both ultimate and fatigue limit states. The reliability analysis is conducted by the use of first order reliability method (FORM). The general methods and techniques utilized for risk and reliability assessment are presented in the following sources [6,7,8]. It is further noted that a probabilistic approach linked with fracture mechanics models for crack development can be used as basis for reliability- and risk-based planning of inspections and maintenance.

1.1. Wind turbine drivetrain

The low speed rotations of the turbine's hub are transformed into electrical energy, by the use of the wind turbine drivetrain. Generally, wind turbine drivetrain module is mounted onto the bedplate of the wind turbine nacelle and contains the following components: main bearings, main shaft, gearbox, brake, and generator [9]. The wind turbine drivetrain with the aforementioned configuration can be seen in Fig. 1.

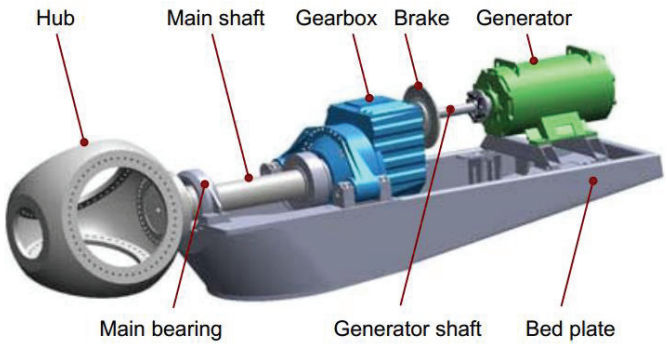

Fig. 1. General wind turbine drivetrain configuration [9].

The drivetrain module components are subjected to highly dynamic and random cycling loading through its lifetime, hence failures in both ultimate and fatigue limit states are relevant for their design.